UCID- 21105

DEFINITION OF A MEASURE OF MATERIAL DISPERSITY IN LOW DENSITY MATERIALS

Richard M. Christensen

July 7, 1987

Lawrence Livermore National Laboratory

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

DISCLAIMER

DEFINITION OF A MEASURE OF MATERIAL DISPERSITY

IN LOW DENSITY MATERIALS

Richard M. Christensen

Lawrence Livermore National Laboratory
Livermore, CA

Abstract

A definition is given of material dispersity for low density materials which reflects the scale of material distribution in three-dimensional space. The measure of dispersity involves both cell size and cell type. The closed cell type is shown to provide a finer scale of material distribution than does the open cell type. A trade off between cell size and cell type is quantified.

It is useful to quantify a measure of material dispersity for low density materials. This measure should give an indication degree of fineness or coarseness by which the material is dispersed in three-dimensional space. A specific objective is to discriminate the relative merits of open cell versus closed cell materials with regard to the uniformity of material dispersal or distribution.

Obviously, cell size is the main characteristic by which material dispersal can be controlled. In the following definition of material dispersal, however, cell size will be taken to be a fixed parameter. That is to say, a measure of material dispersity will be defined which reveals the trade-off between cell size and cell architecture, namely that of open versus closed cell type.

For a given control volume of low density material, define the parameter η by

$$\eta = \frac{\text{Volume of Material}}{\text{Surface Area of Material Microstructure}} .$$

The parameter η is seen to be an index of the material dispersal, the larger the index, the less dispersed is the material. Normalize the volume to that of a unit cell, thus

$$\eta = \frac{\text{Vol. Mat./Vol. Cell}}{\text{Area Mat./Vol. Cell}}$$

The quantity in the numerater is just the non-dimensional volume fraction of the material. Designate the material volume fraction by c, then

$$\eta = \frac{c}{\text{Area Mat./Vol. Cell}}$$

The next step is to give the quantity in the denominator a specific form. This is accomplished through the use of the unit cell in the form of a dodecahedron. The geometry for this type of unit cell is worked out in UCRL-93443, "Mechanics of Low Density Materials", and it applies for both open and closed cell type micro-structures. In the open cell case the edges of the dodecahedron are taken to be the micro-member struts, and in the closed cell case the faces are the micro-member membranes. Take the characteristic length of the single edge of the dodecahedron as parameter "a". This is a measure of the cell size and it could be converted to an effective cell diameter, although that is not necessary for the present purposes. From UCRL-93443 the volume of the dodecahedron is given by

$$\text{Vol Cell} = 7.663\ a^3$$

while the surface area corresponding to the membrane area in the closed cell case is given by

$$\text{Membrane Area per Cell} = 20.165a^2$$

In the open cell case from UCRL-93443

$$\frac{r}{a} = .4939\ \sqrt{c}$$

where r is the radius of the individual strut. The area of the strut is then given by

$$\text{Strut Area} = 2\pi ar$$

Taking 30 struts per unit cell and 1/3 of each strut being associated with a single cell, it then follows that

$$\text{Strut Area per Cell} = 31.03\ a^2\sqrt{c}$$

Combining all of the above results then gives

$$\eta\Big|_{\substack{\text{Closed}\\\text{Cell}}} = .3711\ ca$$

and

$$\eta\Big|_{\substack{\text{Open}\\\text{Cell}}} = .2470\ \sqrt{c}\ a$$

These are the material dispersal indices in terms of the volume fraction of material, c, and the characteristic cell size, a.

Take the ratio of the above quantities to give

$$\frac{\eta_{\text{Open Cell}}}{\eta_{\text{Closed Cell}}} = \frac{.6656}{\sqrt{c}}$$

Further take typical volume fractions of interest in the range of 1% to 3%. Then

$$\left.\frac{\eta_{\text{Open Cell}}}{\eta_{\text{Closed Cell}}}\right|_{c\,=\,.03} = 3.844$$

and

$$\left.\frac{\eta_{\text{Open Cell}}}{\eta_{\text{Closed Cell}}}\right|_{c\,=\,.01} = 6.658$$

It is seen that the closed cell micro-structure gives a more efficient material dispersal. In the volume fraction range cited above, the ratio of efficiencies is about a factor of 5. That is, a closed cell material of 10 μm cell size would have the same material dispersal index as an open cell material of 2μm cell size. At the same cell size, the closed cell material is about 5 times more effective than the open cell material in the sense of the material dispersal index defined herein. This difference becomes even greater as the volume fraction of material is diminished.

ACKNOWLEDGMENT

The question of characterizing a measure of material dispersity was raised by M. O. Riley. A helpful discussion with him is appreciated.